Energy Efficiency Evaluation Framework for Ultra Dense 5G RAN

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Content

The University Of Sheffield. EPSRC Engineering and Physical Sciences Research Council SERON Seamless and Adaptive Wireless Access for Efficient Future Networks Research Project

Introduction

❖ Future 5G RAN expectations

- Higher capacity expectation
- Lower energy consumption expectation
- Densified macro-RANs no longer meet these expectations
- Densified small cell RANs become appealing

❖ Ambiguity in the energy efficiency (EE) metric

- EE metric in [bit/J]
- No indication of respective capacity and energy consumption conditions
- A comprehensive framework required

System Model

❖ Network architecture

- Base station (BS) technologies: macro-/micro-/pico-BSs
- User equipment (UE) density of 300 UEs per km^2 (medium traffic intensity), and camp to the nearest BS
- Schedulers: Round Robin (RR), Maximum SINR (MSINR) and Proportional Fair (PF)

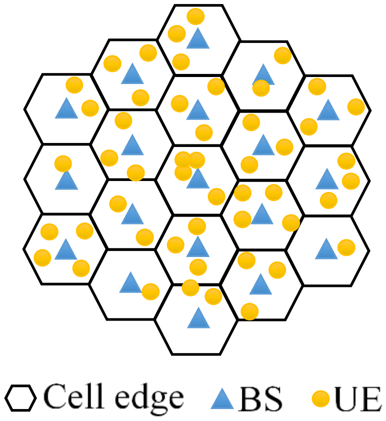

Figure 1. RAN schematic

❖ Channel model

- Downlink (DL) of the Long Term Evolution (LTE) network
- Path loss model [1]

$$PL^{(x)} = \beta^{(x)} + \zeta^{(x)} log_{10}(dist),\ x = LoS\ or\ NLoS$$

$\beta^{(x)}$ is a dimensionless constant
$\zeta^{(x)}$ is the path loss exponent
$dist$ is the distance between terminals

- Multipath fading: identical and independent distribution (i.i.d) in the frequency domain, and Doppler fading in the time domain

[1] 3GPP, "TR 36.828: 3rd generation partnership project; technical specification group radio access network; evolved universal terrestrial radio access (E-UTRA); further enhancements to LTE Time Division Duplex (TDD) for Downlink-Uplink (DL-UL) interference management and traffic adaptation (release 11)", V11.0.0, 2012-06

System Model

❖ **Systematic parameter table**[1]

BS technology	Macro	Micro	Pico
BS/UE Height [m]	15/1.5	4.5/1.5	3/1.5
Carrier frequency [GHz]	2	2	2
Channel bandwidth[MHz]	20	20	20
RB number/TTI	100	100	100
Maximum antenna gain [dBi]	16	9	0
$\beta^{(LoS)}$	30.8	34.02/4.02	41.1
$\zeta^{(LoS)}$	24.2	22/40	20.9
$\beta^{(NLoS)}$	2.9	30.5	32.9
$\zeta^{(NLoS)}$	42.8	36.7	37.5

[1] 3GPP, "TR 36.828: 3rd generation partnership project; technical specification group radio access network; evolved universal terrestrial radio access (E-UTRA); further enhancements to LTE Time Division Duplex (TDD) for Downlink-Uplink (DL-UL) interference management and traffic adaptation (release 11)", V11.0.0, 2012-06

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System Model

❖ BS power consumption model

- BS architecture[2]
  - Consists of backhaul, power supply, cooling system and radio frequency (RF, includes baseband, transceiver, power amplifier) units

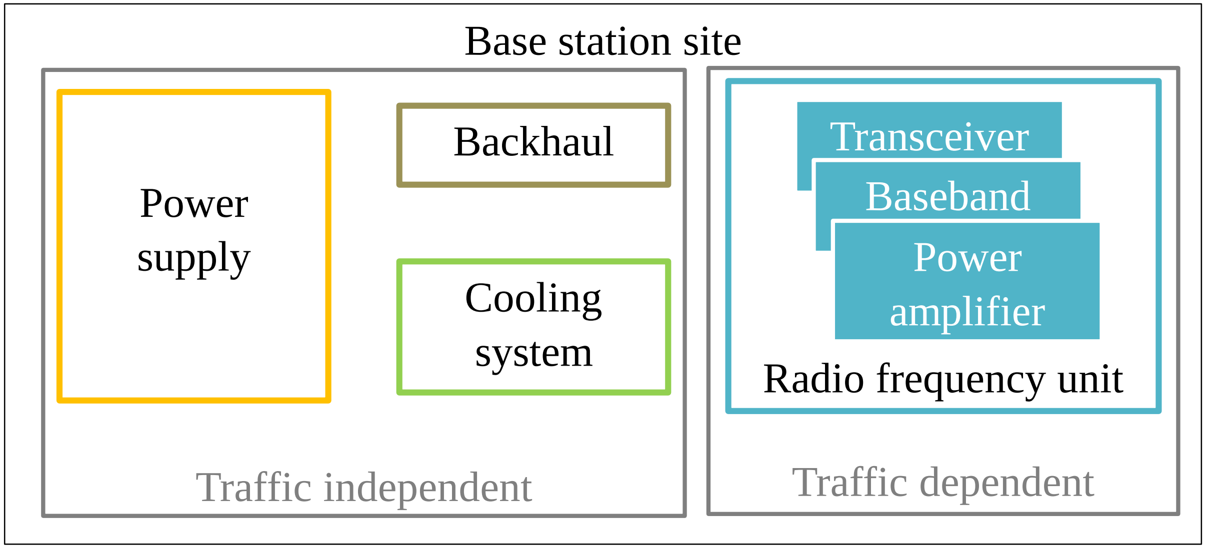

Figure 2. Base station architecture

[2] Abdelrahman Arbi, Timothy O'Farrell, Fu-Chun Zheng and Simon Fletcher, "Toward Green Evolution of Cellular Networks by High Order Sectorisation and Small Cell Densification", in *Interference Mitigation and Energy Management in 5G Heterogeneous Cellular Networks*, Jan 2017

System Model

❖ BS power consumption model

- Formula derived and enhanced from the Green Radio Project[2]

$$P_{site} = P_{bh} + \left(\frac{3.4121}{EER}+1\right)\frac{n_s n_t}{\eta_{ps}}(\hat{P}_{bb}+\hat{P}_{trx}) + \frac{n_s n_t \hat{P}_{tx}}{\eta_{cl}}\left[\left(\frac{3.4121}{EER}+1\right)\frac{\sqrt{\alpha OBO}}{\eta_{ps}\hat{\eta}_{pa}} - \frac{3.4121}{EER}\alpha\right]$$

$$OBO = \frac{P_{sat}}{\hat{P}_{tx}} \qquad \eta_{pa} = \sqrt{\frac{P_{tx}}{P_{sat}}}\hat{\eta}_{pa} \qquad P_{tx} = \alpha \hat{P}_{tx}$$

- Power parameters table

BS technologies	Macro	Micro	Pico
backhaul power P_{bh} [W]	10	10	10
energy efficiency ratio EER (cooling)	11	-	-
sector/antenna count per site n_s/n_t	1/1	1/1	1/1
peak baseband power $\hat{P}_{bb}$ [W]	30	27	3
peak transceiver power $\hat{P}_{trx}$ [W]	13	6.5	1
peak transmission power $\hat{P}_{tx}$ [W]	40	6.3	0.13
cable efficiency η_{cl}	0.5	0.79	1
power supply efficiency η_{ps}	0.85	0.85	0.85
peak power amplifier (PA) efficiency $\hat{\eta}_{pa}$ (%)	70	77	93
normalised traffic load activity factor α	100%	100%	100%/10%

[2] Abdelrahman Arbi, Timothy O'Farrell, Fu-Chun Zheng and Simon Fletcher, "Toward Green Evolution of Cellular Networks by High Order Sectorisation and Small Cell Densification", in *Interference Mitigation and Energy Management in 5G Heterogeneous Cellular Networks*, Jan 2017

System Model

❖ BS power consumption model

- Power model traffic-dependent characteristics

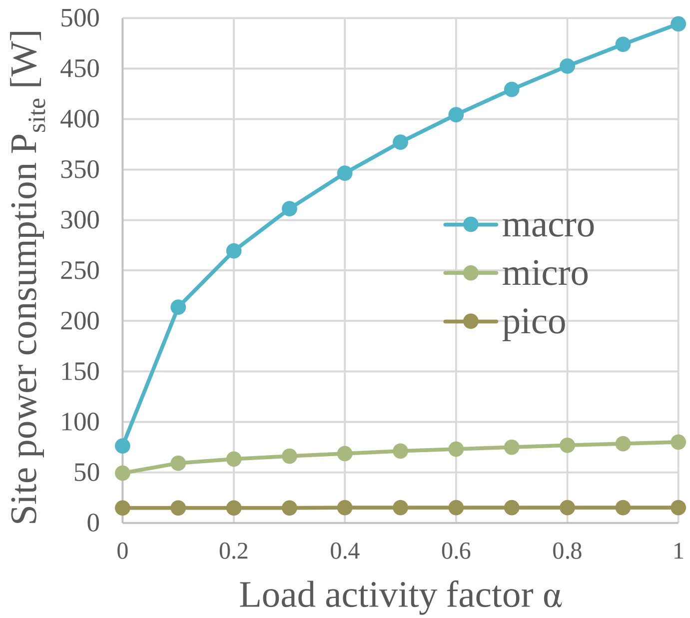

Figure 3. Site power consumption against load activity factor, OBO = 6.32

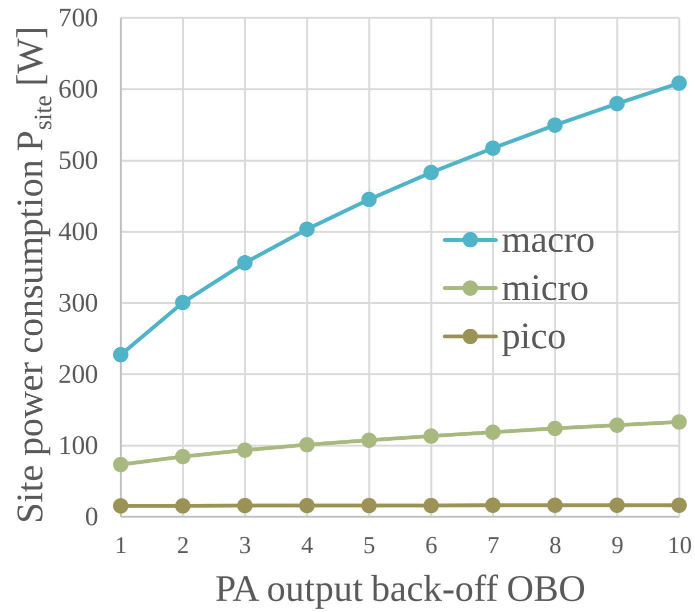

Figure 4. Site power consumption against OBO, α = 1, fixed $\hat{P}_{tx}$

Energy Efficiency Evaluation Framework

- **Include capacity, energy consumption, and energy efficiency performance**
- **Metrics:**
  - S_i = throughput of RAN i in $[bit/s]$, $i = 1, 2$
  - P_i = power consumption of RAN i in $[W]$, $i = 1, 2$
  - A_i = area of RAN i in $[m^2]$, $i = 1, 2$
- **Existing energy efficiency metric:** $EE = \frac{S_i}{P_i}$
- **Proposed ratio based figures of merit[3]**
  - Data Volume Gain: $DVG = \frac{S_2/A_2}{S_1/A_1}$
  - Energy Consumption Gain: $ECG = \frac{P_1/A_1}{P_2/A_2}$
  - Energy Efficiency Gain: $EEG = ECG \times DVG = \frac{S_2/P_2}{S_1/P_1}$

[3] Timothy O'Farrell and Simon Fletcher, “Categorization of green communication concepts", 1st Ed, John Wileys & Sons. Ltd, 2015, Chap 2

RAN Densification Results

- **Reference case:** macro-RAN with inter site distance (ISD) of 500m, RR scheduling
- **Experiment A:** Homogeneous RAN densification with different BS technologies (macro-/micro-/pico- RAN), scheduled by RR

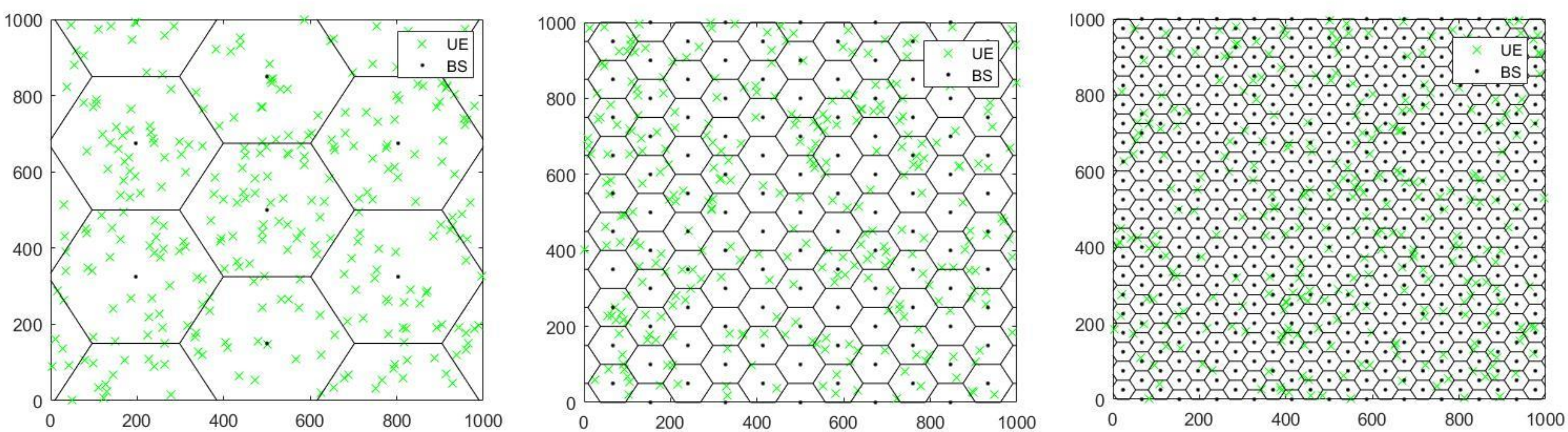

Figure 5: Homogeneous RAN schematic of ISD 350m (left), 100m (middle), and 50m (right), equivalently to 10, 100, and 460 cells per km^2

RAN Densification Results

❖ **Experiment A:** Homogeneous RAN densification with different BS technologies (macro-/micro-/pico- RAN), scheduled by RR

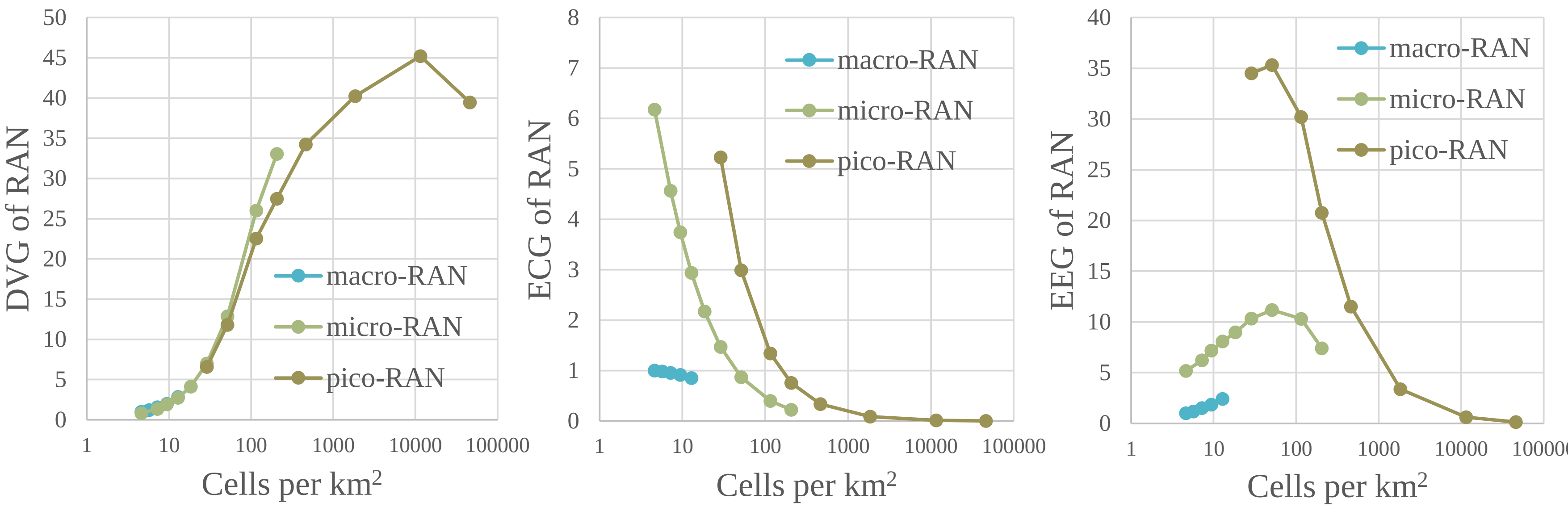

Figure 6: Figure of merit results of homogeneous network densification comparing BS technologies

❖ Remarks:

- Optimum cell density at 10,000 cells per km^2 for DVG due to LoS interference
- ECG reduces continuously due to the increasing in the cell count
- Optimum cell density at 80 cells per km^2 for EEG due to the massive ECG reduction exceeding DVG improvement

Scheduling Results

- **Reference case:** macro-RAN with inter site distance (ISD) of 500m, RR scheduling
- **Experiment B:** Homogeneous pico-RAN densification with different schedulers (MSINR, RR, PF)

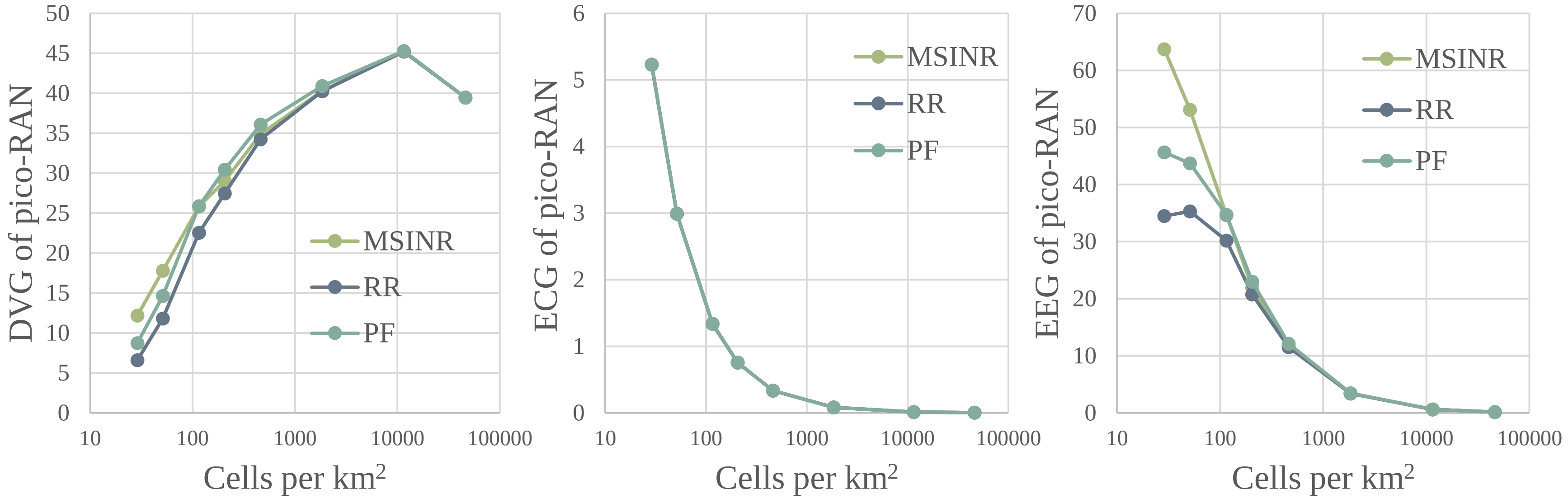

Figure 7: Figure of merit results of homogeneous network densification comparing schedulers

- **Remarks:**
  - Scheduling gains in DVG and EEG converge at approximately 2000 cells per km^2 due to the lack of user diversity
  - Scheduling does not affect ECG when all RBs are used

Conclusions

- Small cell RANs have better performance than macro-RANs
- RAN Densification
  - Enhances pico-RAN capacity up to 45x with RR at ISD of 10 m
  - Further densification leads to capacity degradation due to LoS interference and distance limitation
- Scheduler
  - User diversity gain in capacity and energy efficiency: up to 1.8x and 1.3x for MSINR and PF, respectively, comparing with RR at low and medium cell density
  - No impact on RAN energy consumption
- Next step: heterogeneous network with sparse small cell deployment

Thank you !

Any questions?